M.O. 668

THE METEOROLOGICAL MAGAZINE

January 1960 No. 1,050, Vol. 89

Price 2s. 6d. Net.

CONTENTS

JANUARY 1960

NOTICES

It is requested that all Books for Review and Communications for the Editor be addressed to the Director-General, Meteorological Office, Air Ministry, Headstone Drive, Harrow, Middlesex, and marked "for Meteorological Magazine".

The responsibility for facts and opinions expressed in the signed articles and letters published in this magazine rests with their respective authors.

All enquiries relating to the insertion of advertisements in the Meteorological Magazine should be addressed to the Director of Publications, H.M. Stationery Office, Atlantic House, Holborn Viaduct, London E.C.1. (Telephone: CITy 9876, extn. 147).

Printed in England by Geo. Gibbons Ltd. Leicester
and published by
HER MAJESTY'S STATIONERY OFFICE

Price 2s. 6d. **Annual subscription 32s. including postage**

S.O. Code No. 40-43-60-1

M.O. 668 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 89, No. 1,050, January 1960

MODIFICATION OF WARM MARITIME AIRSTREAMS OVER EUROPE IN WINTER

By I. J. W. POTHECARY, B.Sc.

Summary.—125 occasions were selected when stable warm maritime air moved over cold ground in winter; 12-hour trajectories were computed and the change in thickness in the 1000–500-millibar layer determined. Estimates were made of the net flux of heat into or out of the layer due to long-wave and solar radiation and evaporation and were compared with the observed thickness changes. By night the estimated mean heat flux was -194 cal. cm.$^{-2}$ (12 hr.)$^{-1}$ while the mean observed thickness changed by -41 m. (12 hr.)$^{-1}$ (equivalent to a temperature change throughout the layer of -2°C.). By day during the midwinter period the corresponding figures were -120 cal. cm.$^{-2}$ (12 hr.)$^{-1}$ and -25 m. (12 hr.)$^{-1}$. There was, however, a large scatter of values about the mean and, after discussing possible causes of this, the conclusion was reached that dynamical processes were important, even though the cases were selected as far as possible to minimize these effects. An incidental result of some interest was that the net loss of heat by long-wave radiation from the 1000–500-millibar layer in warm stable airstreams was largely independent of the amount of cloud below 5,000 feet.

Introduction.—The changes in the thermal structure of air masses which have become slow moving or stationary over regions different in character from their sources have been extensively described, but less information is available on the changes which take place in airstreams in transition between the major source regions. Craddock[1] used radio-sonde data to obtain measurements of the rates at which arctic airstreams moving south over the warmer Atlantic received heat and water vapour from the sea, and Burbidge[2] described changes in westerly continental polar airstreams crossing the Hudson Bay. Both studies were concerned with the modifying effects of the considerable transfer of heat by convection from the surface into the colder airstreams.

The modification of stable airstreams passing over cooler surfaces would be expected to be much smaller in the absence of the convective transfer of heat from the surface. The modifying processes, apart from dynamic changes, are essentially non-adiabatic. The heat balance is determined primarily by radiation and the changes in the thermal structure of the airstreams are almost entirely due to the slow eddy transfer of heat.

The results presented in this paper are an assessment of the magnitude of the changes in the heat balance of warm stable air moving over cold ground based on certain broad assumptions about the radiative character of the 1000–500-millibar layer. The changes in the thickness of this layer reflect the loss or gain of heat. For forecasting purposes thickness change is probably the most useful

parameter by which the results of the physical processes concerned in the modification of an airstream can be described.

Selection of data.—Dynamical processes leading to subsidence or ascent are capable of producing considerable changes in the thermal structure of a stable air mass. It is difficult to estimate the magnitude of such changes so the present study is confined to cases in which dynamical effects were thought to be unimportant. The temperature structure of the airstreams should have been changed only by non-adiabatic processes.

Occasions were chosen from the winter months of October to March (1947–1957) when warm maritime air penetrated into continental Europe. Using a suitably placed radio-sonde observation as a starting point, 12-hour trajectories were drawn for the surface air and that at 500 millibars using the analysed charts. To eliminate the occasions when vertical motion might have produced important changes in the thermal structure of the 1000–500-millibar layer the trajectories were rejected if they became involved in frontal zones or if precipitation or convective cloud was reported in the surface observations. Trajectories were also rejected if they passed over ground higher than 1,000 metres or became markedly curved. The occasions eventually used in the analysis were those which survived these limitations and also fulfilled the condition that after 12 hours the end points of the surface and 500-millibar trajectories should not be more than 150 miles apart. Almost all the occasions were found in wide warm sectors well south of depression centres. The strong westerly flow covered from 400 to as much as 700 miles in 12 hours. The trajectories were classed as "day" or "night" trajectories, depending on whether the origin was at an 0300 or 1500 G.M.T. radio-sonde observation. Sixty-two of the occasions were "day" trajectories and 63 were "night" trajectories.

The basic data for each occasion consisted of a mean 12-hour cloud cover, based on three-hourly surface observations along both trajectories, and the difference between the 1000–500-millibar thickness at the origin and the mean of the thickness at the two end points of the trajectories.

Modifying processes.—The thermal modification of a layer of stable warm air overlying cold ground is determined primarily by radiation, by the loss of heat due to evaporation at the surface, and by the balance between heat brought down to the ground surface by eddy diffusion and conducted into the ground and the heat flow by eddy diffusion through the top of the layer. The outgoing radiative flux is determined by the long-wave radiation from the underlying surface, assuming that the heat radiated away is supplied by the overlying air, and by the distribution of cloud and water vapour in depth through the atmosphere. During the day loss of heat by long-wave radiation is offset by incoming short-wave solar radiation which depends on the time of year, the amount and type of cloud and the albedos of the surface and cloud top.

Evaporation at the ground surface will absorb a certain amount of heat. In the stable airstreams considered the heat used in evaporation and the heat passing into the ground are brought to the surface by eddy diffusion which will depend on the temperature gradient near the ground. There will also be a transfer of heat by eddy diffusion through the 500-millibar level.

Modification by radiation.—The long-wave radiative heat flux at various levels in the atmosphere can be conveniently calculated by Elsasser's graphic methods, using radio-sonde data for pressure, temperature and humidity.

Calculations of the radiative heat flux at various levels up to 450 millibars were made for several of the occasions chosen for analysis in order to establish the magnitudes of the heat fluxes and the variations between different occasions. The calculations shown in Table I are for an occasion when the airstream was cloudy for the first nine hours and clear for the last three hours. During the cloudy period the cloud base was at 850 millibars and the cloud top at 820 millibars.

TABLE I—RADIATIVE HEAT FLUX IN WARM MARITIME AIR

Brussels, 1500 G.M.T., 11 November 1953			Heat flux (+ve upwards)	
			Cloudy	Clear
Pressure	Temperature	Relative humidity	1500–0001 G.M.T.	0001–0300 G.M.T.
mb.	°*C.*	*gm. kg.* $^{-1}$	*cal. cm.* $^{-2}$ *hr.* $^{-1}$	
surface	7·3	5·40	1·2	6·0
956	4·7	4·90	1·1	6·4
949	6·2	5·30	1·5	7·5
850	0·1	4·00	1·4	8·4
820	−0·8	4·00	7·4	8·4
784	3·7	2·50	8·4	9·2
717	−0·1	1·20	10·1	10·9
646	−2·2	1·30	11·9	12·4
500	−13·8	0·62	14·5	14·8
445	−18·9	0·36	15·1	15·5

Table I shows that the presence of cloud below about 5,000 feet makes very little difference to the upward flux of heat through the 500-millibar layer. The reason for this is that while in the absence of cloud the main radiating surface (the ground surface) is at a higher temperature than that of a cloud top, the outgoing radiation from the ground has to pass through a greater depth of water vapour. This conclusion was confirmed in the other cases for which the Elsasser calculation was carried out. It appeared that the variations from case to case of the long-wave flux through the 500-millibar layer were small enough to be disregarded, and a rate of 15 cal. cm. $^{-2}$ hr. $^{-1}$ (giving a total loss of 180 cal. cm. $^{-2}$ in 12 hours) has been adopted in all cases.

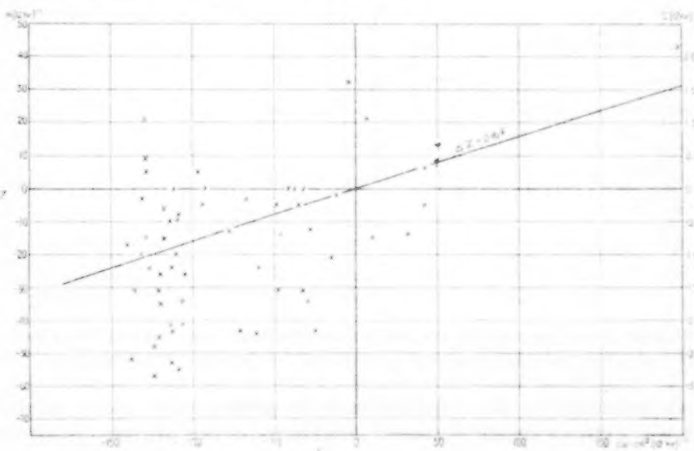


FIGURE 1—THICKNESS CHANGES AND CALCULATED NET HEAT FLUX VALUES FOR 62 "DAY-TIME" AIRSTREAMS

The loss of heat by long-wave radiation is offset during the day by incoming short-wave solar radiation. A curve of the solar radiation incident at the top of the atmosphere was constructed for the six-months period and the relevant value for each occasion was extracted. It was assumed that 90 per cent of this radiation reached the top of the layer 500 millibars to surface, and that of this 90 per cent 60 per cent was reflected when there was 8-eighths cloud in the layer and 20 per cent was reflected in cloudless conditions. Hence the fraction of the total solar radiation available for heating the air between the surface and 500 millibars varied between 36 per cent and 72 per cent according to the cloud cover. Radiation absorbed by the ground was assumed to be utilized in heating the overlying air and in evaporating surface moisture (see the next section).

Modification by evaporation.—The loss of heat by evaporation was based on five years (1949–54) of evaporation data for Kew for the six months from October to March.

TABLE II—HEAT ABSORBED BY EVAPORATION

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Mean evaporation (mm.)	27·9	13·7	9·9	9·4	12·5	29·0
Heat absorbed (cal. cm.$^{-2}$ (12 hr.)$^{-1}$)	26·7	13·7	9·5	9·0	13·3	27·8

A curve was constructed from the evaporation figures for each month from which the appropriate heat absorption values were obtained for each occasion. The mean evaporation is likely to be a reasonable representation of conditions in the warm maritime airstreams analysed as the loss of heat by evaporation

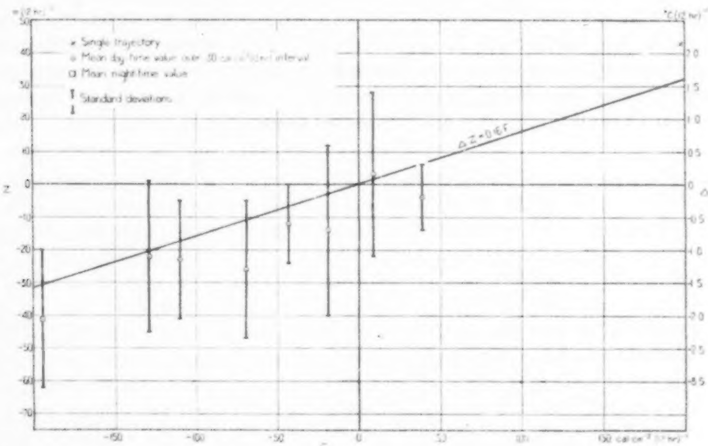


FIGURE 2—MEAN VALUES OF THICKNESS CHANGES AND CALCULATED NET HEAT FLUX VALUES OVER 30 CAL. CM.$^{-2}$ (12 HR.)$^{-1}$ INTERVALS

depends primarily on the humidity and the surface wind speed, neither of which was extreme on the occasions considered in this analysis. Evaporation was assumed to continue at the same rate by night as by day. The surface observations along the trajectories showed that there was generally only a small diurnal variation in wind speed or temperature.

Calculation of the net heat balance.—The basic data for each occasion consisted of the 12-hour 1000–500-millibar thickness change in the airstream, the mean cloudiness, the amount of insolation and the heat used in evaporation (Table II).

The principal assumptions may be summarized as follows:

(*a*) Fraction of extra-terrestrial radiation reaching 500-millibar level with no higher cloud ... ... 0·9

(*b*) Albedo of surface and atmosphere below 500 millibars

  (i) with 8-eighths cloud ... ... 0·6

  (ii) with no cloud ... ... 0·2

(*c*) Constant long-wave radiative loss (independent of cloud amount) ... 180 cal. cm. $^{-2}$ (12 hr.) $^{-1}$

(*d*) Heat loss due to evaporation ... ... as Table II

Figure 3 shows the net heat flux to be expected on the above assumptions on any winter night or day with or without low cloud. The curves were drawn using the values for mid-month, the calculations being shown in Table IV. The net heat flux (*F*) for any given occasion was determined from Figure 3, an appropriately weighted mean of the overcast and cloudless values being used for the day trajectories.

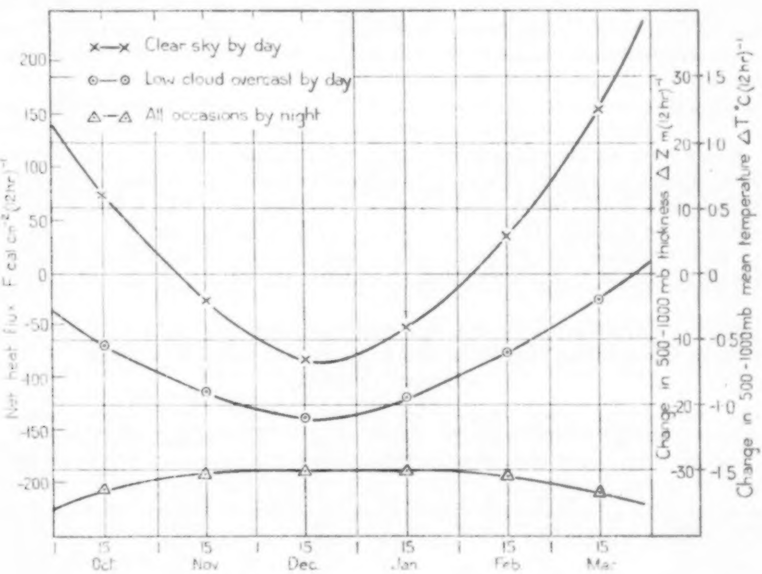


FIGURE 3—NET 12-HOUR HEAT FLUX DUE TO RADIATION AND EVAPORATION AND CORRESPONDING THICKNESS AND TEMPERATURE CHANGES IN THE 1000–500-MILLIBAR LAYER

A scatter diagram showing the relation between the observed thickness change and the calculated heat flux for the 62 day-time occasions is at Figure 1. On over half the occasions, which all fell within the period mid-November to late

January, the calculated heat flux lay in the range −105 to −140 cal. cm. $^{-2}$ (12 hr.) $^{-1}$. The observed thickness changes on these day-time occasions had a mean value of −25 m. (12 hr.) $^{-1}$ (equivalent to a temperature change of $-1\frac{1}{4}$°C. per 12 hours) and a range extending from +21 to −57 m. (12 hr.) $^{-1}$. By night the calculated heat flux varied between −215 and −189 cal. cm. $^{-2}$ (12 hr.) $^{-1}$ while the observed thickness changes ranged from zero to −102 m. (12 hr.) $^{-1}$ with a mean value of −41 m. (12 hr.) $^{-1}$. The results were combined by calculating the mean heat flux and mean thickness change for intervals of 30 cal. cm. $^{-2}$ (12 hr.) $^{-1}$ in the heat flux, these and the standard deviations of the thickness change being shown in Table III and Figure 2.

TABLE III—MEAN HEAT FLUX (F) AND 1000–500-MILLIBAR THICKNESS CHANGE (Δz) VALUES OVER 30 CAL. CM. $^{-2}$ (12 HR.) $^{-1}$ INTERVALS IN THE HEAT FLUX

Mean heat flux F cal. cm. $^{-2}$ (12 hr.) $^{-1}$	Change in 1000–500 mb. thickness Δz m. (12 hr.) $^{-1}$	Mean temperature change in 1000–500 mb. layer ΔT °C.	Number of occasions n	Standard deviation of thickness change m
−194	−41	−2·0	63	22
−129	−22	−1·1	14	23
−110	−23	−1·1	21	18
−69	−26	−1·3	4	21
−43	−12	−0·6	11	12
−19	−14	−0·7	6	26
+9	+3	+0·1	2	25
+39	−4	−0·2	3	10
+198	+43	+2·1	1	—

A column of air extending from 1000 to 500 millibars and with a cross-section of one square centimetre receiving 100 calories of heat will increase in thickness by 16 metres and its mean temperature will increase by 0·8°C. For comparison purposes the relation $\Delta z = 0 \cdot 16F$ (where Δz is in metres and F is cal. cm. $^{-2}$ (12 hr.) $^{-1}$) is shown on Figures 1 and 2, and scales of the thickness change Δz and temperature change ΔT have been added at the right-hand side of Figure 3.

TABLE IV—CALCULATION OF THE NET HEAT BALANCE AND ASSOCIATED CHANGES IN 1000–500-MILLIBAR THICKNESS AND MEAN TEMPERATURE IN A WARM MARITIME AIRSTREAM

Date	Period	Cloudiness by day %	Solar radiation at 500 mb. cal. cm. $^{-2}$ (12 hr. $^{-}$) ^{1}	Absorbed with clear sky: 20% albedo cal. cm. $^{-2}$ (12 hr.) $^{-1}$	Absorbed with 8/8 cloud: 60% albedo cal. cm. $^{-2}$ (12 hr.) $^{-1}$	Lost by long-wave radiation cal. cm. $^{-2}$ (12 hr.) $^{-1}$	Lost by evaporation cal. cm. $^{-2}$ (12 hr.) $^{-1}$	Net heat balance cal. cm. $^{-2}$ (12 hr.) $^{-1}$	12-hour change in 1000 to 500-mb. thickness Δz m	12-hour change in 1000 to 500-mb. mean temp. ΔT °C.
15 Oct.	day	0	350	+279	0	−180	−27	+72	+12	+0·6
	day	100	350	0	+140	−180	−27	−67	−11	−0·5
	night	—	0	0	0	−180	−27	−207	−33	−1·7
15 Nov.	day	0	210	+169	0	−180	−14	−25	−4	−0·2
	day	100	210	0	+84	−180	−14	−110	−18	−0·9
	night	—	0	0	0	−180	−14	−194	−31	−1·6
15 Dec.	day	0	135	+108	0	−180	−10	−82	−13	−0·6
	day	100	135	0	+54	−180	−10	−136	−22	−1·1
	night	—	0	0	0	−180	−10	−190	−30	−1·5
15 Jan.	day	0	171	+137	0	−180	−9	−52	−8	−0·4
	day	100	171	0	+68	−180	−9	−121	−19	−0·9
	night	—	0	0	0	−180	−9	−189	−30	−1·5
15 Feb.	day	0	286	+228	0	−180	−13	+35	+6	+0·3
	day	100	286	0	+115	−180	−13	−78	−12	−0·6
	night	—	0	0	0	−180	−13	−193	−31	−1·6
15 Mar.	day	0	456	+364	0	−180	−28	+156	+25	+1·2
	day	100	456	0	+182	−180	−28	−26	−4	−0·2
	night	—	0	0	0	−180	−28	−208	−33	−1·7

Discussion of results.—The scatter diagram (Figure 1) shows that there is only a loose relation between the net heat flux, as derived from this analysis, and the observed 12-hour 1000–500-millibar thickness change in the warm maritime airstreams considered, but the statistical analysis (Figure 2) shows, nevertheless, that the relation is real. The mean values of the net heat fluxes and thickness changes are reasonably aligned with the theoretical relation $\Delta z = 0 \cdot 16F$, although, as can be seen from Figure 2, there is a noticeable tendency for the computed heat losses to be underestimated. Some of the factors which may have contributed to the large scatter are considered briefly below.

The assumptions about transmission coefficients and albedos used in calculating the heat changes due to radiation were based on the best available estimates and, together with the long-wave radiation value, are not likely to be greatly in error except when cloud other than stratocumulus below about 800 millibars was present. The heat losses due to evaporation are likely to have differed somewhat from the average values assumed, but even if evaporation were absent the effect on the 1000–500-millibar thickness change would amount to only six metres in October or March and two metres in December or January.

Two other heat transfer processes which could be effective in changing the mean temperature (and thickness) of the 1000–500-millibar layer are eddy diffusion of heat through the 500-millibar surface and the conduction of heat into the ground. No estimate could be made of the magnitude of the first, though it seems likely to be small. Some detailed measurements of earth temperature to a depth of one metre at Berlin on an occasion of strong warm air advection showed that about 10 cal. cm. $^{-2}$ were conducted into the ground during 12 hours. This would lead to a thickness change of less than two metres.

The formation and dissipation of cloud would also produce heat changes. The release of latent heat as a saturated cloud layer 30 millibars deep cools by about 2°C. amounts to about 15 cal. cm. $^{-2}$. The evaporation of 30 millibars of stratocumulus cloud will need about 2 cal. cm. $^{-2}$. The amounts of heat are small, so no attempt was made to take these processes into account in the analysis. Some errors in the estimation of the observed thickness changes will have occurred due to inaccurate trajectories, other trajectories will not have been representative of the true motion of the air if ageostrophic effects were present. Inaccuracies in the thickness changes may also have arisen from variations between the different types of radio-sonde in use.

Even if correct allowance could be made for all the above factors it seems likely that an appreciable scatter would remain. Although the method of selection of the cases was designed to exclude airstreams in which vertical motion would be effective in changing the thermal structure, the criteria could not be absolutely rigorous and it is evident that dynamical processes still played a significant part.

REFERENCES

1. CRADDOCK, J. M.; The warming of arctic air masses over the eastern North Atlantic. *Quart. J. R. met. Soc., London*, **77**, 1951, p. 355.

2. BURBIDGE, F. E.; The modification of continental polar air over Hudson Bay. *Quart. J. R. met. Soc., London*, **77**, 1951, p. 365.

3. HAURWITZ, B.; Insolation in relation to cloud. *J. Met., Lancaster, Pa.*, **5**, 1948, p. 110.

THE CLEARANCE OF WATER FOG FOLLOWING THE ARRIVAL OF A CLOUD SHEET DURING THE NIGHT

By W. E. SAUNDERS, B.Sc.

In a recent paper[1] attention was called to the effects produced by a sheet of cloud spreading over an existing radiation fog at Exeter. It was pointed out that in a large proportion of cases fog cleared following the arrival of cloud. Generally, the lower the cloud, the more certain and rapid was the clearance. In the present note an attempt is made to separate the cases in which fog cleared from those in which it failed to do so, and so provide a basis for forecasting the clearance or persistence of water fog on occasions when a cloud sheet is expected to arrive.

It was pointed out[1] that the most significant temperature change following the arrival of cloud was usually a rapid rise near the ground. The main physical causes leading to this will be reduction of the net outgoing radiation due to arrival of cloud cover and the fact that heat flux is still upwards in the soil near the ground surface. This heat flux now serves to raise the temperature of the ground surface and of the air near the ground, instead of merely reducing the rate of fall of temperature as it does under full nocturnal outgoing radiation conditions.

The effect of the cloud is to set up downward radiation which was not present when the sky was clear. The net outgoing radiation is reduced to an amount which depends very largely on the height of the cloud and its temperature. This is illustrated by some figures given by Brunt,[2] quoting Asklöf:[3]

Cloud type	Net outgoing radiation *gram calories per square centimetre per minute*
Ns, St, Sc	0·023
Ac	0·039
Cs	0·135
clear sky	0·169

It follows that the cloud height is a significant parameter.

The heat transfer in the soil follows the physical laws of conduction. It was commented in the earlier article[1] that, before the cloud arrived, the soil temperature at two inches was always higher than the grass temperature, and the temperature at eight inches was higher than at two inches. Hence, at the time of arrival of cloud, the heat flux is always directed upwards towards the ground surface. The rate of transfer of heat upwards depends on the difference of temperature in the soil layer, on physical properties of the soil—its density, specific heat and conductivity—and on its condition. The rate of flow will be more rapid if the soil is wet than if it is dry. It will also vary according as the soil is or is not frozen at the initial time, being slower if it is frozen, because of the loss of heat in melting ice in the soil. Clearly, therefore, the nature and state of ground must be taken into account. In the present work the nature of soil is taken into account by using the results from one site only (Exeter), and the results will be somewhat modified on different types of soil.

With regard to the clearance of fog, it is assumed the rise of temperature near the ground is sufficient to evaporate all the fog droplets and to raise the air temperature sufficiently to accommodate the additional water vapour. The higher the initial temperature, the smaller is the necessary rise of temperature

for this latter purpose. We should therefore expect to find fog clearance proceeding more rapidly the higher the initial temperature.

Arising from the theoretical ideas outlined above, additional temperature observations were made near the ground at Exeter Airport, as already mentioned in the earlier article.[1] The records of all occasions in which a cloud sheet was observed to move over an existing fog were examined. Cases where there was evidence of a freshening wind clearing the fog or lifting it to stratus cloud were excluded for the present investigation. Cases where fog clearance could possibly be due to insolation were of course omitted.

The cloud heights were mostly measured by searchlight. Cloud amounts were treated in a common-sense way. To initiate the mechanism described above the cloud must obviously be overhead, but from examination of past records it is never possible to be certain it was overhead unless the amount was reported as eight-eighths. In the present investigation the cloud was assumed to have cleared the fog if the cloud amount was six-eighths or more, the fog cleared and the behaviour of the temperatures near the ground was in accord with the pattern already described.[1] If the fog did not clear the case was not included unless the cloud amount was eight-eighths or there were only very small breaks recorded as over seven-eighths.

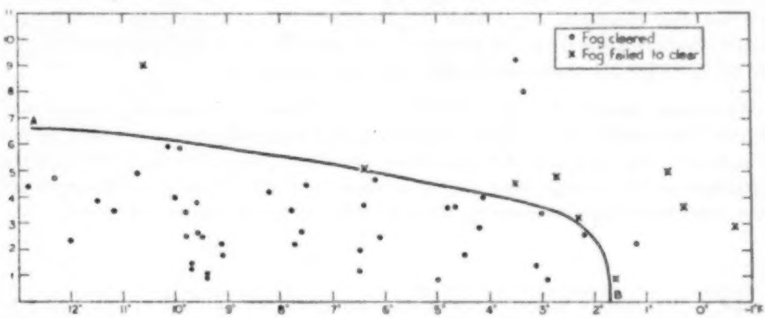


FIGURE 1—RELATION OF FOG CLEARANCE, FOLLOWING THE ARRIVAL OF CLOUD, TO CLOUD HEIGHT AND SOIL-TO-AIR TEMPERATURE GRADIENT

Three "×" cases under cirrostratus cloud above 20,000 feet are not plotted.
Cloud height in thousands of feet
Soil temperature at 2 in. minus air temperature in screen before the arrival of cloud

In Figure 1 the parameters used are cloud height and the soil-to-air temperature gradient immediately before the arrival of cloud. The latter is expressed as the soil temperature at two inches minus the air temperature in the screen. It appears that on Figure 1 a line AB can be drawn to separate most of the cases in which fog cleared (small circles) from those in which it failed to do so (marked ×). Of the three "o" cases shown above and to the right of AB, two were very recently formed thin fogs.

The main result which emerges from Figure 1 is that the continuous sheets of stratocumulus cloud which are commonly encountered beneath anticyclonic inversions will cause fog clearance unless initially the ground-to-air temperature difference is small.

In the application of Figure 1 in forecasting there are certain difficulties. The two-inch soil temperature is not at present measured as routine at airfields. If Figure 1 is applied for forecasting purposes elsewhere, the following points require to be borne in mind:–

(i) The cases included in this investigation were those in which the fog was thin enough vertically for the arrival of cloud to be observed. Some cases were noted where a "sky obscured" fog cleared to reveal a sheet of cloud, and while it might be inferred that the cloud had caused the fog clearance these cases were not included owing to lack of information about the time of arrival of cloud. If there were any means of including these deeper fogs the position of AB on Figure 1 would doubtless be different.

(ii) The fogs at Exeter are water fogs. There is no reason to suppose that fog containing a higher proportion of solid particles could be cleared as rapidly, or at all, in the manner described.

(iii) The line AB reflects the soil characteristics of Exeter, and may be differently placed on other types of soil.

The time taken for fog to clear following the arrival of cloud was also examined. On some occasions this appears to be an almost instantaneous process. For example, on 3 May 1957 with visibility 150 yards the observer noted "Sc spreading from NE at 0525", followed by "Fog clearing slowly 0535". By the next hourly observation visibility was 1,600 yards.

As already mentioned, the rate of rise of temperature near the ground will depend materially on the state of ground, and especially upon whether or not it is frozen. Accordingly, the cases have been grouped in Table I to show the variation of the average time for fog to clear with the initial grass temperature (the grass thermometer reading immediately before the arrival of cloud).

TABLE I—VARIATION WITH GRASS-LEVEL TEMPERATURE OF TIME TAKEN FOR FOG TO CLEAR FOLLOWING THE ARRIVAL OF CLOUD

Initial grass temperature °F.	Number of cases	Average time for fog to clear *hours*
Below 32	10	3·1
32–36	10	2·2
37–41	5	1·1
42–46	10	1·5
47–51	5	0·9
52–56	3	0·5

The results show that the time taken varies with temperature in the manner to be expected from the theoretical considerations outlined above.

REFERENCES

1. SAUNDERS, W. E.; Variation of visibility in fog at Exeter Airport, and the time of fog dispersal. *Met. Mag., London*, **86**, 1957, p. 362.

2. BRUNT, D.; Physical and dynamical meteorology. Cambridge, 1939, p. 144.

3. ASKLÖF, S.; Über den Zusammenhang zwischen der nächtlichen Wärmeausstrahlung, der Bewölkung und der Wolkenart. *Geogr. Ann., Stockholm*, **2**, 1920, p. 253.

COTSWOLDS SNOWFALL OF 1 NOVEMBER 1942

By F. E. LUMB, M.Sc.

Introduction.—In the Cotswolds area (see Figure 1) on 1 November 1942 continuous precipitation fell from 0300 to 1500 G.M.T.; at Gloucester (15 metres above sea level) entirely in the form of rain; at Aston Down (180 metres) and Upper Heyford (130 metres) mainly as rain but occasionally as sleet; and at Little Rissington (230 metres) as rain from 0300 to 0740 G.M.T., as sleet from 0740 to 1000 G.M.T. (approximately) but entirely as snow after 1000 G.M.T. By 1300 G.M.T. wet snow was lying to a depth of two inches.

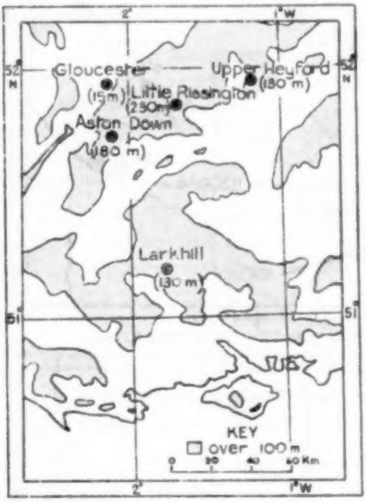


FIGURE 1—COTSWOLDS AREA

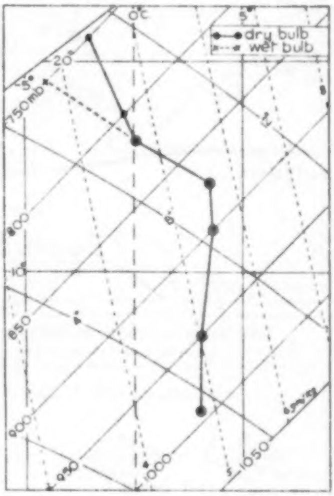


FIGURE 2—TEPHIGRAM FOR LARKHILL, 1100 G.M.T., 1 NOVEMBER 1942

Figure 2 is the upper air sounding at Larkhill, 80 kilometres to the south of Little Rissington, at 1100 G.M.T. on 1 November 1942. The wet-bulb freezing level was 820 millibars. Hence snow was falling at Little Rissington when the wet-bulb freezing level only 80 kilometres to the south was 1,500 metres above the level of Little Rissington (980 millibars).

Douglas[1] has stated that when the wet-bulb freezing level is above 600 metres the great bulk of precipitation over the British Isles falls as rain. The snow at Little Rissington appears to be a most remarkable exception to this generalization, and evidently deserves closer examination.

Synoptic situation.—Figures 3 and 4 show the synoptic situation at 0700 and 1300 G.M.T. on 1 November 1942. Rain had reached south-west England around midnight and moved north-north-east with the upper winds during the day.

The winds at Larkhill at 1100 G.M.T. were as in Table I.

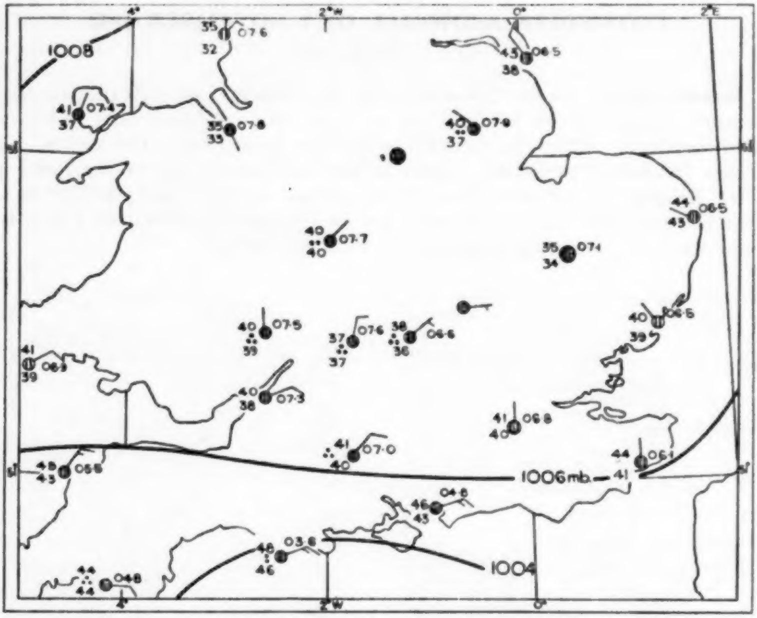


FIGURE 3—SYNOPTIC CHART FOR 0700 G.M.T., 1 NOVEMBER 1942

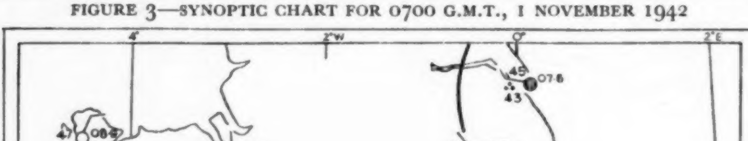


FIGURE 4—SYNOPTIC CHART FOR 1300 G.M.T., 1 NOVEMBER 1942

TABLE I—WINDS AT LARKHILL, 1100 G.M.T.

Height mb.	Direction deg.	Speed m. sec.$^{-1}$
950	050	8
900	060	8
850	200	8
800	200	10
750	200	11
700	210	12

There was a strong thermal wind of 230° 15 metres per second between 900 and 850 millibars, corresponding to a steep horizontal temperature gradient of 1°C. per 10 kilometres. Since Larkhill is 80 kilometres almost due south of Little Rissington, this temperature gradient could make the mean temperature between 900 and 850 millibars 6°C. lower at Little Rissington than at Larkhill.

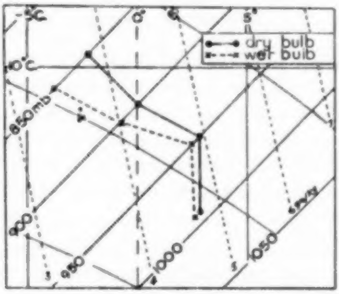


FIGURE 5—TEPHIGRAM FOR LARKHILL, 2000 G.M.T., 1 NOVEMBER 1942

By 2000 G.M.T. the upper air sounding at Larkhill was as shown in Figure 5, and the lower winds were as in Table II.

TABLE II—WINDS AT LARKHILL, 2000 G.M.T.

Height mb.	Direction deg.	Speed m. sec.$^{-1}$
950	340	11
900	340	12
850	340	12

Evidently between 1200 and 2000 G.M.T. colder air had reached Larkhill from the north at all levels between 950 and 850 millibars. At 2000 G.M.T. the mean wet-bulb temperature between 900 and 850 millibars was −2°C., 5°C. lower than at 1100 G.M.T. The air over the Cotswolds at 1100 G.M.T. would be saturated since it is clear from Figures 3 and 4 that it had been subject to several hours' cooling by precipitation, and it can be deduced from graphs given by Dolozel[2] and Best[3] that cooling by evaporation during continuous moderate rain will reduce the difference between the dry- and wet-bulb temperatures to less than one-tenth of its original value in two to four hours. Since there was little movement of the air over the Cotswolds at low levels during the morning, it is probable that the wet-bulb curve at Larkhill at 2000 G.M.T. is a close approximation to the temperature curve (with saturated air) at Little Rissington at 0740 G.M.T. when rain changed to sleet.

The wet-bulb freezing level at Larkhill at 2000 G.M.T. was 910 millibars, that is, 600 metres above Little Rissington (980 millibars). The change to sleet is now seen to be just consistent with Douglas's statement. Since the precipitation

intensity towards 0800 G.M.T. increased to between 3 and 4 millimetres per hour (see Figure 6), some of the snowflakes would be very large, and it is not surprising that they were able to fall through the extreme depth of 600 metres before completely melting.

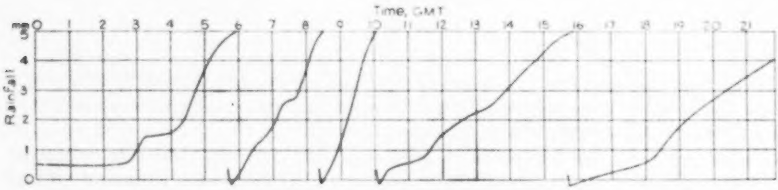


FIGURE 6—HYETOGRAM FOR LITTLE RISSINGTON, 0000–2200 G.M.T. 1 NOVEMBER 1942

Cooling of air column to isothermal at 0°C.—Once thawing snowflakes reach the ground, the cooling effect on the overlying air is important. Provided there is no advection of uncooled air from outside the precipitation area, or of air warmed over the sea, simultaneous cooling by thawing from above and below tends to produce an isothermal layer at 0°C. from the ground to the freezing level. As this cooling proceeds, precipitation eventually falls as snow at all levels down to the ground.

Figures 3 and 4 show that on 1 November 1942 conditions over the Cotswolds were very favourable for this cooling process to take full effect. The temperature at Little Rissington when sleet began at 0740 G.M.T. was 2·8°C. (37°F.)—see Figure 7. Sleet had changed to snow by 1000 G.M.T., and the temperature had fallen to about 0°C. by 1030 G.M.T. There was continuous moderate or heavy snow from 1000 G.M.T. to 1500 G.M.T. The change of precipitation intensity shown by the hyetogram at 1030 G.M.T. was probably caused by the accumulation of snow in the rain-gauge, and marks the time when thawing of snow during its descent had ceased at all levels.

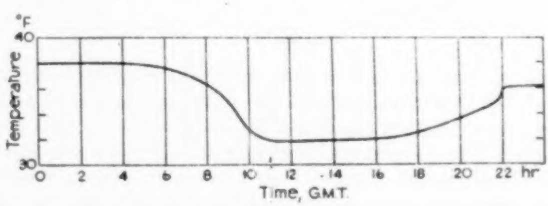


FIGURE 7—THERMOGRAM FOR LITTLE RISSINGTON, 1 NOVEMBER 1942

The evidence therefore strongly suggests that by 1030 G.M.T. the air column at Little Rissington from the ground to the freezing level had been cooled at all levels to 0°C.

Calculation of cooling by thawing.—The amount of rain which fell at Little Rissington between 0740 and 1030 G.M.T. was 7·5 millimetres (see Figure 6). If the wet-bulb curve at Larkhill at 2000 G.M.T. was in fact a good approximation to the temperature curve at Little Rissington during the period of cooling by thawing (0740 to 1030 G.M.T.), then the thawing of snow equivalent

to 7·5 millimetres of rain should be approximately sufficient to reduce the wet-bulb curve at Larkhill at 2000 G.M.T. (from 980 to 910 millibars) to isothermal at 0°C.

The heat abstracted from the air by the thawing of the snowflakes is used not only to lower the temperature of the air but to annul the gain of heat by condensation as the saturated air is cooled. Hence the heat balance equation for a column of unit cross-section extending vertically from z_0 to z_1 is:

$$L_f\ (P_r \times 10^{-1}) = C_p \int_{z_0}^{z_1} \Delta T.\ \rho\, dz\ +\ (L_e \times 10^{-3}) \int_{z_0}^{z_1} \Delta q_s.\ \rho\, dz, \quad \ldots\ldots (1)$$

where

L_f = latent heat of fusion
P_r = precipitation in millimetres
C_p = specific heat of air at constant pressure
ΔT = fall of temperature at level z
ρ = air density
L_e = latent heat of evaporation
Δq_s = change of saturation specific humidity (grams per kilogram)
z_0, z_1 refer to ground and freezing level respectively.

Over the small range of pressure and temperature with which we are concerned $\Delta q_s = 0{\cdot}33\ \Delta T$ (to a close approximation). Also

$$\int_{z_0}^{z_1} \Delta T.\ \rho\, dz = -\left(\frac{1}{g}\right) \int_{p_0}^{p_1} \Delta T.\ dp$$

$$= \frac{\overline{\Delta T} \times 10^3}{g}\ (p_0 - p_1), \quad \ldots\ldots (2)$$

where g is the acceleration of gravity, $\overline{\Delta T}$ is the fall of temperature of the air column meaned with respect to pressure, and p_0, p_1 are the pressures (in millibars) corresponding to the levels z_0, z_1.

Substituting $0{\cdot}33\ \Delta T$ for Δq_s in equation (1) and using equation (2), equation (1) becomes

$$P_r = \frac{10^4\ \overline{\Delta T}\ (p_0 - p_1)\ [\,C_p + (0{\cdot}33 \times 10^{-3})\ L_e\,].}{g\ L_f} \quad \ldots\ldots (3)$$

Substituting appropriate values for C_p, L_e, g, L_f in equation (3) we find

$$P_r = 0{\cdot}056.\overline{\Delta T}\ (p_0 - p_1). \quad \ldots\ldots (4)$$

Application to 1 November 1942.—In Figure 5 the mean wet-bulb temperature from 910 to 980 millibars is 1·8°C. Using equation (4) we find that the thawing of the equivalent of 7·1 millimetres of rain is necessary to cool this column to be isothermal at 0°C.

The calculated value is therefore in good agreement with the amount of rainfall (7·5 millimetres) measured at Little Rissington during the period 0740 to 1030 G.M.T., and is confirmatory evidence that the wet-bulb curve at Larkhill at 2000 G.M.T. is a good approximation to the temperature curve (with saturated air) at Little Rissington when rain changed to sleet at 0740 G.M.T.

Summary.—A cursory examination of the synoptic charts for 0700 and 1300 G.M.T. on 1 November 1942, and of the Larkhill upper air sounding at 1100 G.M.T., suggests that the snow at Little Rissington had penetrated downwards 1,500 metres below the wet-bulb freezing level. A closer examination of the evidence shows that it is most unlikely that the snow penetrated downwards more than 600 metres (70 millibars) below the wet-bulb freezing level.

REFERENCE

1. DOUGLAS, C. K. M.; Some problems of snow forecasting. 1950 (unpublished, copy available in Meteorological Office Library).
2. DOLEZEL, E. J.; Saturation and cooling of air layers by evaporation from falling rain. *J. Met., Milton, Mass.*, **1**, 1944, p. 89.
3. BEST, A. C.; The evaporation of raindrops. *Quart. J. R. met. Soc., London*, **78**, 1952, p. 200.

MAN-MADE CUMULUS

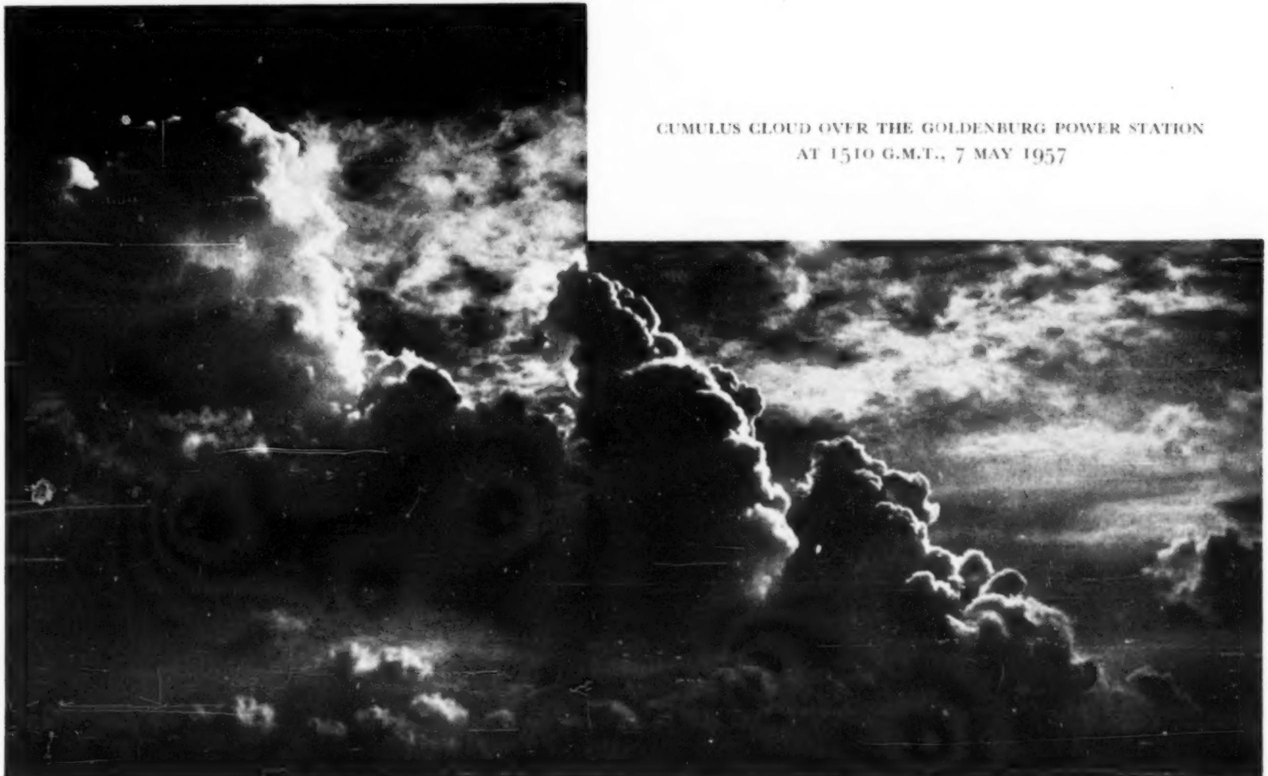
By G. J. JEFFERSON, M.Sc.

The occurrence of cumulus and cumulonimbus clouds over man-made sources of surface heating is well known. A particularly good example of its frequent formation occurs over the Goldenburg Power Station which lies at Knapsack, about six miles south-west of Cologne, Germany. The very frequent occurrence of convection cloud over this particular power station is most noticeable and appears to be due not only to the heat given off but also to the large amount of moisture released, some of which can nearly always be seen as "steam" and which must cause an appreciable local rise in surface dew-point. It is safe to say that convection cloud is visible on well over 50 per cent of occasions when the state of sky makes its observation possible. On some occasions cumulonimbus cloud and showers occur. The shape and vertical extent of the cloud gives a very good idea of the thermal structure of the first few thousand feet of the air.

The photograph facing p. 16 was taken at 1510 G.M.T. on 7 May 1957 and was the best obtained in over two years of observation. The power station, which was about 4½ miles to the west-south-west of the camera, can be seen in the bottom right-hand corner, while the clouds appear to be moving away in a south-easterly direction. A fresh cumulus tower formed every few minutes moving off with the wind as it grew. Three towers in various stages of growth are visible in the photograph.

The synoptic situation at the time showed rather weak pressure gradients over north-west Europe with low pressure over eastern Europe and a depression near southern Greenland. Higher pressure over the Norwegian Sea extended a wedge south over the British Isles while fronts lying north to south were almost stationary over Ireland. At 500 millibars there was a deep elongated trough over Scandinavia extending southwards to east Germany. The 7th May was the last day of a well established northerly flow of Arctic air across the North Sea and Holland into western Germany and was marked with below average surface temperatures. This airstream was still covering the Cologne area at the time of the photograph. Scattered showers of sleet and hail were reported in the surrounding area during the day and a few places on higher ground had snow.

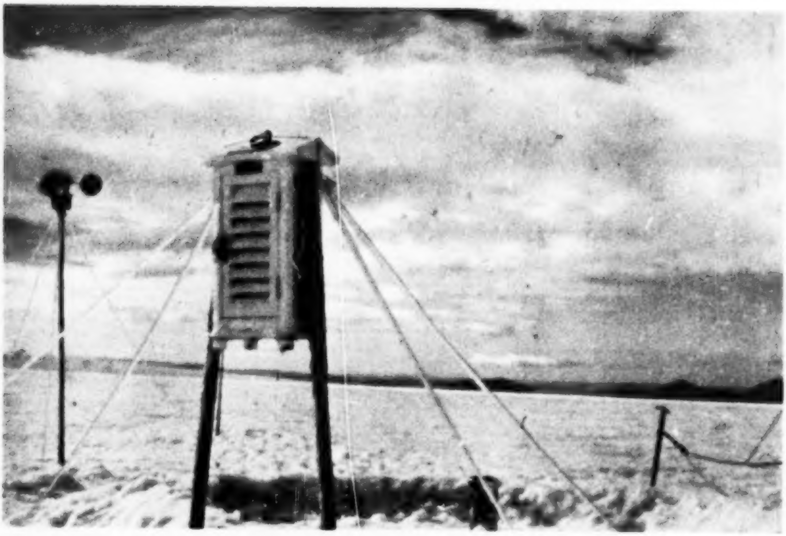
The sounding for De Bilt for 1200 G.M.T. on the same day is fairly well representative of the air over Cologne at 1500 G.M.T. (the wind at 500 millibars was 340° 50 knots). This sounding shows a lapse rate exceeding the saturated adiabatic up to 650 millibars; above this level was a stable layer to 500 millibars.



CUMULUS CLOUD OVER THE GOLDENBURG POWER STATION
AT 1510 G.M.T., 7 MAY 1957

Photograph by G. J. Jefferson

[To face p. 16

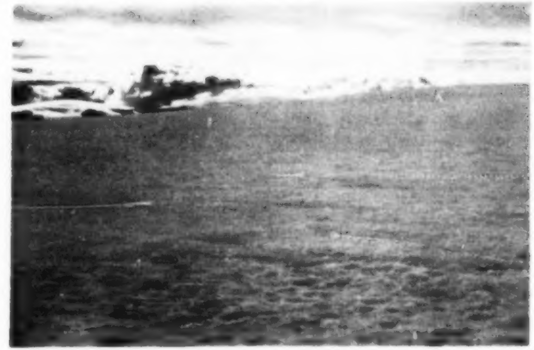


Photograph by F. G. Hannell

GLAZED FROST AT STATION D

(see p. 17)

Photograph by F. G. Hannell



Photograph by F. G. Hannell

Photograph by F. G. Hannell

DEVELOPMENT OF CUMULUS OVER THE SURROUNDING DESERTS, AS SEEN FROM STATION D

(see p. 17)

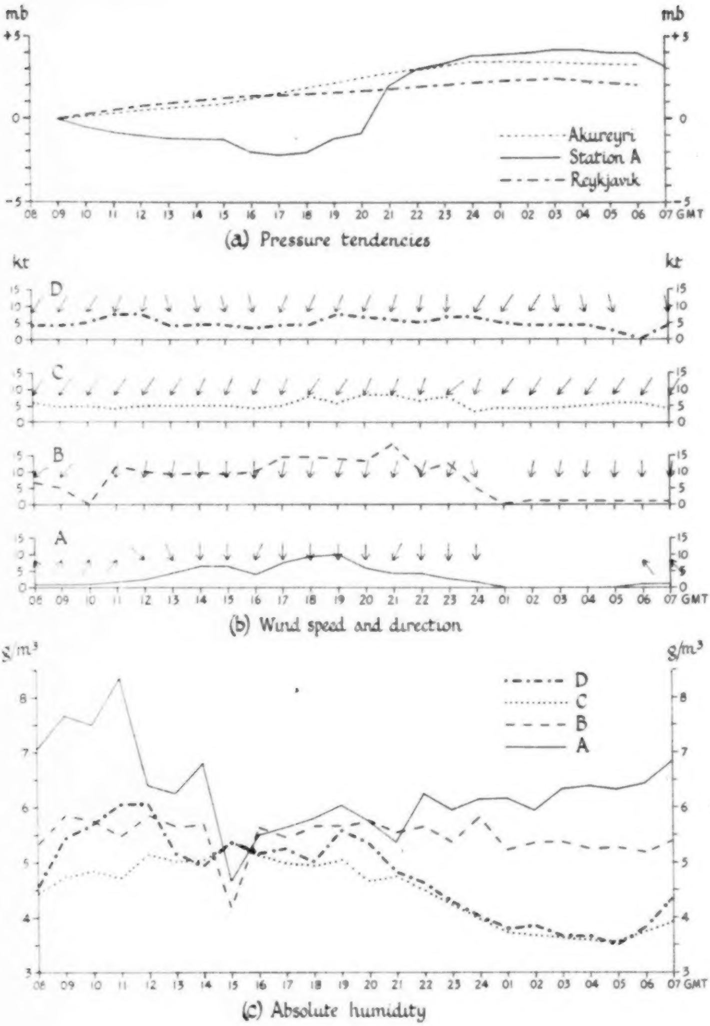


FIGURE 1—HOURLY OBSERVATIONS OF PRESSURE, WIND AND ABSOLUTE HUMIDITY, 15–16 AUGUST 1956

This stable layer (between approximately 12,000 and 18,000 feet) is probably marked by the broken altocumulus seen in the photograph above the main cloud.

The use of simple photogrammetric methods has enabled estimates to be made of the height of the cumulus tops. The only uncertain parameter in these computations is the wind direction which was not known exactly over Cologne at the time. The calculated heights of the tops of the three main cumulus heads visible in the photographs are 6,040 feet, 8,910 feet and 12,470 feet if the wind with which they are drifting is assumed to be from 310 degrees. With a wind of 320 degrees the corresponding heights are 6,430 feet, 9,870 feet, and 14,850 feet respectively.

At 1500 G.M.T. the surface temperature at Bonn, a few miles to the south, was 6°C. and the dew-point 3°C. This would give weak convection from the ground and would account for the other rather shallow cumulus in the sky at the time, some of which is visible in the photograph. So far as could be ascertained, the clouds in the photograph did not give showers while still within visual range though they may have done so later.

WIND AND TEMPERATURE VARIATIONS AT THE EDGE OF AN ICE-CAP

By I. Y. ASHWELL, M.A., and F. G. HANNELL, B.Sc., Ph.D.

During August and September 1956 some of the members of the British Schools Exploring Society's eighteenth Expedition undertook certain meteorological tasks in central Iceland.[1] In an earlier paper by the same authors[2] it was stated that during spells of comparatively quiet weather with northerly winds and clear skies, fluctuations in temperature and humidity which were experienced in the morning and at night over that portion of the central desert lying immediately to the south of Langjökull were associated with changes of airflow in the area of the ice-cap edge. The present paper constitutes a brief examination of such events under similar weather conditions.

The ice-cap stations.—Four recording stations, A, B, C and D, were used in the investigation of meteorological conditions on the ice-cap. A map of the area showing the location of these stations, together with an account of their establishment and the routine adopted at each, has appeared elsewhere.[1]

Descriptions of the surface features in the neighbourhood of A, the Expedition's main meteorological station at an elevation of 335 metres, and of the instruments which were installed at this site, were included in the earlier paper.[2] Station B, at a height of 905 metres, was sited on the boundary between glacier ice and firn near the north end of Hagafell, a flat-topped basalt mountain which projects above the surface of Langjökull. Station C was placed half-way up the south-facing slope of the ice-cap at an elevation of 1,145 metres, whilst station D (1,330 metres), at the head of that slope and six miles north of B, was intentionally located just short of the summit (1,345 metres). To the north of station B there were considerable stretches of surface with an average gradient of one in ten, but at the higher levels slopes were less steep.

The items of meteorological equipment installed at each of the ice-cap stations were identical. Owing to the difficulty experienced as a result of the heavy deposition of glazed frost on the shipboard screens, mounted on deeply embedded bamboo poles, the temperature and humidity measurements

reported below were made with Assman psychrometers held four feet above the surface and the readings reduced with Marvin's tables.

Wind speed was determined by measuring the run for one minute on a cup-counter anemometer mounted nine feet above the surface. At stations B, C and D, wind direction was obtained from a flag, but at station A a sensitive vane was employed for this purpose. Pressure changes at A were measured on a barograph, checked against a good aneroid barometer which had been set by reference to a mercury barometer at Reykjavik. At each of the other stations, pressure readings were taken from an aneroid barometer initially set to agree with that used at A. All times mentioned below are in G.M.T., which is one hour 21 minutes ahead of local mean time.

The photographs between pp. 16, 17 were taken at station D and give a vivid impression of the area. They show the meteorological instruments at D and the development of cumulus over the deserts surrounding the ice-cap.

General weather conditions.—At each of the four stations hourly observations were undertaken, both by day and by night, from 0800, 10 August to 0800, 16 August 1956. The cloudless skies and northerly winds which persisted throughout the period 0800, 15 August to 0700, 16 August provided conditions which were in every respect comparable to those under which observations were made a fortnight later at stations located to the south of the ice-cap.[2] Consequently, this period has been selected for examination in an attempt to illustrate the extent to which meteorological events on the southern slopes of Langjökull and its surrounding deserts are interdependent.

During this 24-hour period pressure was high to the north-west of Iceland, and the gradient wind over the southern half of the country was light easterly. Similar conditions were very frequently experienced during the Expedition's six-week stay in central Iceland, and consequently the phenomena described below are by no means to be regarded as rare occurrences.

Fohn wind.—In their earlier paper concerning meteorological events a fortnight later at stations located to the south of Langjökull,[2] the authors showed that a period of morning calm under cloudless skies led to intense convection over the desert surface. Throughout the afternoon, the pressure at station A was 2·5 millibars below the value recorded at 0900, and mirages and dust-devils were then frequently reported. When convective activity reached a maximum, station A came under the influence of a northerly airstream which had been in contact with the ice-cap's surface, and its arrival between 1400 and 1500 was marked by a drop in temperature. This sequence of events suggested that convective activity over the desert led to the establishment of a pressure gradient which eventually was sufficient to compensate for the blocking action of the ice-cap. Subsequently, air which passed southwards at a height greater than that of the ice-cap's summit was drawn down to the desert stations as a wind of Föhn type, and temperatures there reached a maximum at 1700. Since there is no implication of ascent and precipitation on the windward side of the ice-cap, the term "Föhn wind" is not strictly applicable. However, it is hereafter used to differentiate that descending stream of comparatively warm and dry air which had not been in contact with the ice-cap's surface from those colder and much moister winds from the ice-cap which reached station A at earlier and later times of day.

Throughout the period 15–16 August, which is now under review, conditions were very similar to those outlined briefly above. At station A pressure tendencies from an assumed zero at 0900 on 15 August were as represented in Figure 1 (*a*). This shows that in marked contrast to the gentle rise recorded both at Akureyri on the north coast and at Reykjavik on the south-west coast, the pressure at station A fell to a level which, by 1700, was over two millibars below the figure recorded at 0900. This would seem to indicate that an area of low pressure had developed over the desert to the south-east of Langjökull. Under its influence the winds at A, which throughout the morning had been light and southerly, increased from a northerly quarter during the afternoon and reached their maximum strength of 10 knots at 1900 (Figure 1 (*b*)). During the hour 1300–1400, when these winds first achieved a true north direction, the temperature at station A fell by 1·5°F. before rising to its maximum of 63·8°F. at 1700 (Figure 2(*a*)). Dust-devils over the desert to the south were reported at 1800, 1900 and 2000, and their apparent cessation after the last of these times coincided with a sharp rise in pressure at station A (Figure 1 (*a*)).

This very marked similarity in conditions on two days a fortnight apart suggests that a Föhn wind was also induced on the afternoon of 15 August. However, although the temperature at station A rose to a maximum at 1700, as was the case at each of the desert stations under similar conditions a fortnight later,[2] Figure 2 (*a*) shows that this wind had no effect on the temperatures recorded at the ice-cap stations. Throughout the afternoon and early evening, temperatures there remained below 40°F. and were remarkably steady.

On the accompanying tephigram (Figure 3) the temperatures at each of the four stations at specified times are plotted on their indicated pressure levels. The steep lapse rate between B and A at 1500 on 15 August clearly establishes that although the wind at each of these stations was northerly, the air which arrived at A was not that which had influenced the dry-bulb thermometer at B. In fact, it would seem that very active convection consequent upon the heating of the desert surface[2] resulted in the descent to station A of Föhn air from a height in excess of that of the ice-cap's summit, whereas the surface airstream which affected station B was itself caught up in the convective movement before it passed beyond the ice-cap's margin. The arrival of Föhn air at A is evidenced by the steep decline in absolute humidity at that station between 1400 and 1500 (Figure 1 (*c*)). Moreover, although the temperature there increased steadily between 1500 and 1700, the relative humidity reached its minimum value of 33 per cent at the beginning of this two-hour period (Figure 2 (*b*)).

At B there was no change in wind strength or direction between 1400 and 1500 (Figure 1 (*b*)). However, during this hour the absolute and relative humidity at that station declined sharply to minimum values. This suggests that the moist air in contact with the glacier surface at B was at this time being exchanged with the much drier Föhn air from above. The absence of a concurrent rise in temperature may have been due to rapid evaporation from a surface of ice which, at B and all lower levels, was now very wet.

Movements of air in contact with the south-facing slope of the ice-cap.—Lapse rates at other specified times are shown in Figure 3, and from these certain conclusions may be drawn concerning possible exchanges of surface air between the ice-cap and its surrounding desert. One factor which seemed to be of considerable importance in this connexion was the small fluctuation of

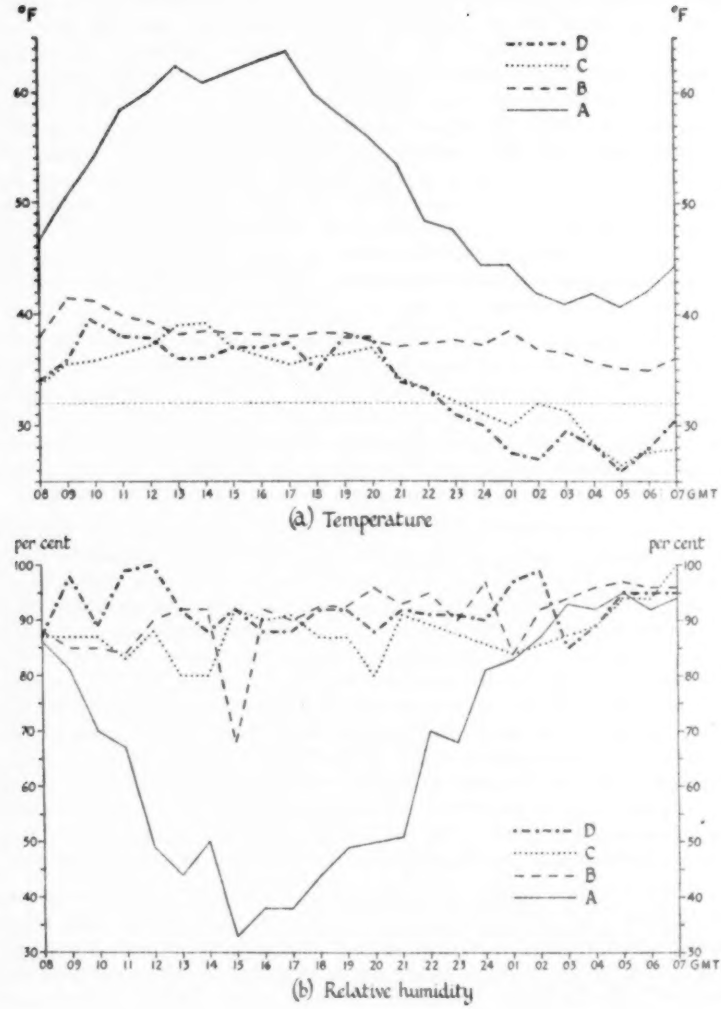


FIGURE 2—HOURLY OBSERVATIONS OF TEMPERATURE AND RELATIVE HUMIDITY, 15–16 AUGUST 1956

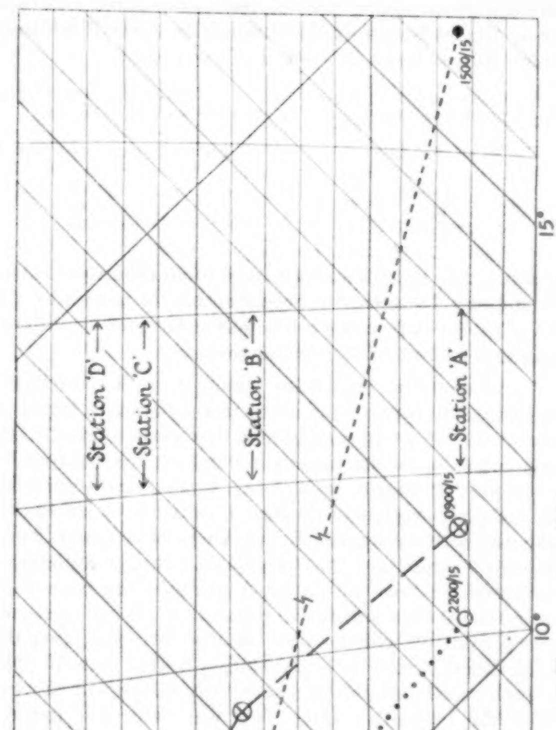


FIGURE 3—TEPHIGRAMS FOR 15–16 AUGUST 1956

temperature at B throughout the 24-hour period as compared with the other stations (Figure 2 (*a*)). This was probably attributable to the difference in the thermal conductivity values shown in Table 1 (Geiger, p. 28[3]).

TABLE I—THERMAL CONDUCTIVITY OF RELEVANT SURFACES

Station	Type of surface	Thermal conductivity (C.G.S. units)
D and C	Old snow	0·0007
B	Ice	0·0055
A	Dry sand	0·0004

The surface at B had a very much larger thermal conductivity value than that at any of the other stations. Thus it seems probable that the lapse rates along the south-facing slope of the ice-cap were very largely influenced by differences in the rates of heating and cooling of the various surfaces.

Under the dry and cloudless conditions which prevailed throughout the period under review, a movement of air up or down the south-facing slope of the ice-cap in contact with its surface could only take place when the lapse rate was approximately equal to the dry adiabatic value. It is seen from Figure 3 that this was the case only at certain times of day. It was certainly not so during the afternoon, for the rapid heating of the desert surface then led to the establishment of a lapse rate between stations B and A which, as exemplified by the plot for 1500, was nearly three times that for dry air. Thus, as explained above, the northerly winds which influenced station A at 1500 were not composed of air which had moved down the south-facing slope of the ice-cap in contact with its surface. It is seen from the plot for 0100 that, consequent upon the more rapid cooling of the desert surface at night, station B soon became potentially warmer than A. Such conditions also precluded any downward movement of air in contact with the ice-cap's surface. Nor was there any movement of saturated air up the slope, for the relative humidity at station A at 0100 was no higher than 83 per cent (Figure 2 (*b*)), and there was certainly no cloud between there and station B. However, when the temperatures over the desert were intermediate between their day and night extremes, the lapse rate between stations was approximately equal to the dry adiabatic value. At such times, as exemplified by the plots for 0900 and 2200 in Figure 3, a movement of air up or down the south-facing slope of the ice-cap in contact with its surface was clearly possible.

On each of 15 days throughout August and early September when cloud amounts were less than four oktas, the interval 2100–2200 marked the arrival at station A of a katabatic wind from the ice-cap's surface, and it was for this reason that the temperature at A fell more sharply during that hour than in any other (Figure 2 (*a*)). Consequent upon the arrival of katabatic air, there was a marked increase in the absolute humidity at station A between 2100 and 2200 (Figure 1 (*c*)). Moreover, it was at the beginning of this hour, when movement down the glacier's surface was in no way impeded, that the wind at B attained its maximum velocity of 18 knots.

At 0900, station A was under the influence of comparatively warm and moist maritime air brought by very light southerly winds (Figure 1 (*b*)). The establishment of a dry adiabatic lapse rate at this time would have allowed such air to move up the south-facing slope of the ice-cap, and this would seem

to account for the sharp increases in temperature and absolute humidity which were recorded at stations B and D between 0800 and 1000 (Figures 2 (*a*) and 1 (*c*)).

Temperature anomalies.—The temperature at station A reached a maximum at 1700 (Figure 2 (*a*)), when the pressure attained its lowest level (Figure 1 (*a*)). Thereafter, convective activity over the desert began to decline, as is evident from a direct investigation of this phenomenon a fortnight later.[2] The Föhn wind drawn down over the desert now came from successively lower levels, and the inclusion therein of air which had been in contact with the upper levels of the ice-cap may have contributed to the fairly steep decline in temperature at station A between 1700 and 2100. Such a loss of air from the ice-cap seems to have been made good, at least in part, by warmer air which had risen from the desert surface, for each of the ice-cap stations experienced an increase of temperature at times between 1700 and 2000, and this was most pronounced at D (Figure 2 (*a*)).

Following the hour 2100–2200, during which a katabatic wind from the ice-cap reached station A, the accumulation of cold air over the desert surface, together with active radiation therefrom, destroyed the dry adiabatic lapse rate which had permitted such a movement. Thereafter station B was potentially warmer than A, as at 0100 in Figure 3, with the result that cold air from the ice-cap could no longer reach the desert surface. This probably accounted for the temperature discontinuity at station A at 2200, which on several other occasions was much more pronounced.

However, the winds at B in Figure 1 (*b*) suggest that a slow katabatic draining of air continued from those portions of the ice-cap's surface which lay above the level of this station. It would seem that this loss was at least partly compensated by a return current of warmer air which lay above the cold surface layer over the desert (Geiger, p. 213[3]). This warmer air reached B between 2400 and 0100, as a result of which the temperatures at this station rose by 1·2°F. during that hour. The plot for 0100 (Figure 3) indicates that there was then instability as between the air at station B on the one hand and that at stations C and D on the other, and this state persisted until 0300. Thus the increase of temperature at C between 0100 and 0200 (2·0°F.), and at D during the succeeding hour (2·5°F.), probably represents the arrival at these higher levels of the warmer air from station B.

Owing to the gentle southerly slope of the desert surface, the layer of cold air in contact with it would not have been able to attain any considerable thickness. It may have broken up on occasions to be replaced by somewhat warmer air from a slightly higher level, and this would account for those fluctuations of temperature which were experienced at station A after 2200 (Figure 2 (*a*)) as well as at other desert stations which were later operated further to the south.[2]

Predominance of northerly winds.—It is seen from Table II that at each of the four stations there was a marked predominance of winds from the northerly quarter. In August and September 1950, the Durham University Exploration Society operated two meteorological stations in this same area; a "Base" station about a mile north of A and a "Top" station in the vicinity of B. In an unpublished report[4] it is stated that winds at the "Base" station were predominantly northerly, and that those at the "Top" station always blew straight off the ice

TABLE II—PERCENTAGE FREQUENCIES OF WIND DIRECTION AND MEAN WIND SPEEDS, 0800, 10 AUGUST TO 0800, 16 AUGUST 1956

(144 hourly observations were made at each station)

Stations	N quarter 315°–45°		E quarter 46°–134°		S quarter 135°–225°		W quarter 226°–314°		Calm
	Frequency %	Mean speed *kt*	Frequency %	Mean speed *kt*	Frequency %	Mean speed *kt*	Frequency %	Mean speed *kt*	Frequency %
D	76	8·3	11	6·6	8	7·5	0	—	5
C	63	9·3	23	7·3	9	8·3	0	—	5
B	79	11·6	9	8·3	4	4·3	0	—	8
A	63	5·8	5	6·2	18	3·5	7	3·3	7

unless disturbed by major frontal influences. The predominance of northerly winds at all levels on the south-facing slopes of Langjökull would seem to be attributable to the frequent development by day of low pressure over the desert to the south and south-east, together with the well marked katabatic draining off the ice-cap during the early hours of the night.

REFERENCES

1. HANNELL, F. G. and ASHWELL, I. Y.; Meteorological studies in Iceland. *Weather, London*, **12**, 1957, p. 365.
2. HANNELL, F. G. and ASHWELL, I. Y.; Meteorological factors in the central desert of Iceland. *Met. Mag., London*, **87**, 1958, p. 353.
3. GEIGER, R.; The climate near the ground. Cambridge (Mass.), 1950, pp. 28, 213.
4. Report of the Durham University Exploration Society's 1950 Expedition to Hagavatn (Iceland). (This was kindly made available by the Society's Student-President.)

LETTER TO THE EDITOR

Visibility and surface wind at Manchester Airport

In Mr. Thomas's article[1] there is one point on which I would like to comment, a point which I think is important in view of the increasing emphasis which is now being given to local investigations of this nature.

Visibility, like rainfall and sunshine, is one of the more variable meteorological elements. Most investigations, of the type in the article, have covered a period of four or five years, but this, in my view, is not nearly long enough to determine the features of the pattern, apart from the broad picture of the annual and diurnal variation, which is usually unmistakable.

According to Bilham[2] "The disadvantages of a short series of observations are felt most acutely when we wish to determine the form of a very variable element like rainfall or the duration of sunshine . . . A comparison of the mean values for Oxford and York for two separate periods of thirty years has shown differences of the order of twenty-five to thirty per cent in certain months."

As I said, visibility is also a very variable element. For example, Evans, in "A second report on fog at London Airport",[3] found that the outstandingly high frequency in November in one period of four years was followed in the next four years by a similar maximum in December. The writers of the original articles on London Airport[4] and Northolt[5] gave "explanations" of the infrequency of fog in December as compared with November.

For Acklington I compared the fog frequencies for two separate periods of six years, 1947–1952 and 1953–1958. I found that in January there were four times as many occasions of fog in the first period as in the second. This was only

one of numerous discrepancies. An important point is that the annual pattern is subject to more variability than the diurnal pattern. The correlation between the sets of monthly totals for the two periods at Acklington was 0·37, while the correlation between the two sets of hourly totals was 0·8.

In the analysis for Manchester Airport, the features referred to at the foot of page 106 are all concerned with thick fog. The percentages involved represent in every case quite small frequencies, twelve or less (0·6 or 0·7 represents one instance, etc.). Now if it is possible to get the large differences which Bilham refers to over periods of thirty years, and if it is possible to get such large variations as Evans obtained at London Airport with monthly totals consisting of three-figure numbers, the variability of the very small numbers involved in the thick fog analysis must be far greater, in proportion. I think that the features referred to are probably not significant at all, and that if a further analysis were done the pattern would be somewhat different.

I am inclined to suspect a number of the explanations given in the fog-frequency articles. Even when the features are found to be really significant, the explanations may not be the correct ones.

I suggest that investigations of this nature should cover as long a period as possible. The Acklington analysis, which was done in a few hours from the files of the monthly returns for the synoptic hours only, is really a better "sample" than the more elaborate analyses done for the other stations. Writers should exercise caution in devizing explanations for minor irregularities. By working out standard deviations it should be possible to tell to some extent whether the differences between months are significant or not.

REFERENCES

1. THOMAS, E. R.; Visibility and surface wind at Manchester Airport. *Met. Mag., London*, **88**, 1959, p. 104
2. BILHAM, E. G.; The climate of the British Isles. London, 1938, p. 13.
3. EVANS, D. C.; A second report on fog at London Airport. *Met. Mag., London*, **86**, 1957, p. 333.
4. DAVIS, N. E.; Fog at London Airport. *Met. Mag., London*, **80**, 1951, p. 12.
5. SAUNDERS, W. E. and SUMMERSBY, W. D.; Fog at Northolt Airport. *Met. Mag., London*, **80**, 1951, p. 255.

Meteorological Office, Acklington. G. A. INGLIS

Reply by E. R. Thomas

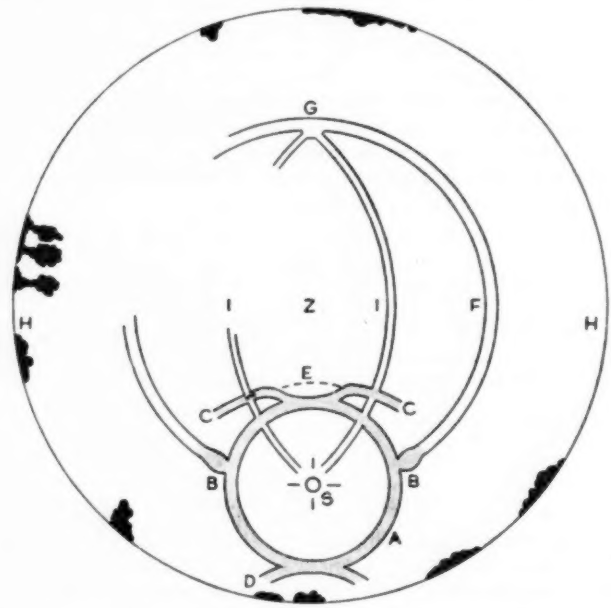
With constantly improving landing aids the thick fog range, 220 yards or less, is now becoming the most important aspect of visibility to aviators. As the investigation was prompted by terminal-forecast and flight-planning considerations, more attention was paid to visibility in this range. As visibility can, and does, vary enormously even between hourly observations, let alone synoptic observations, it seems vital to include as much detail as possible.

It is of course obvious that a long period of observations is much better for such a purpose than a short one, and it is equally obvious that the length of period chosen must be limited by the information available. Taking hourly observations over as long a period as possible means that an individual at an outstation, who has to give priority to his forecasting or other commitments, has an almost impossible task in processing the data. The result is that many investigations, started years ago, remain unfinished.

NOTES AND NEWS

An unusual halo display

On the morning of 5 May 1959, an unusual display of halo phenomena was seen from Lasham, Hampshire, when a sheet of cirrostratus of varying density covered the greater part of the sky. A bright but faintly coloured halo of 22° radius was first observed at 0745 G.M.T. and a brilliantly coloured upper tangent arc to this halo appeared soon afterwards, displaying the sinuous or "cupid's bow" form noted in the great halo display of 2 March 1954.[1, 2] Such was the brilliance of this upper arc that it soon became the focus of public attention. The middle part of this arc, where it dipped to meet the 22° halo, was bridged by a zone of considerable brightness in the position appropriate to the Parry arc. The lower arc of contact to the halo of 22° could be seen by 0800 G.M.T. with most of the parhelic circle and the two parhelia of 22° which were coloured but not unusually bright.



A DISPLAY OF HALO PHENOMENA AS SEEN FROM LASHAM, HAMPSHIRE, 0810 G.M.T., 5 MAY 1959

A, halo of 22° radius, coloured; B, parhelia of 22°, coloured; C, upper tangent arc to 22° halo, brilliantly coloured; D, lower tangent arc to 22° halo, coloured; E, zone of brightness, possibly the Parry arc, white; F, parhelic circle, white; G, anthelion, white; H, horizon; I, oblique anthelic arcs, white; S, sun; Z, zenith.

For a short time, from 0805 to 0815 G.M.T., the anthelion appeared with its brightness elongated for about 10° on either side along the parhelic circle. At

the same time two wide angle oblique anthelic arcs were evident as white but distinct lines stretching across the sky from the anthelion to the sun. The arc passing to the north of the zenith was incomplete. These anthelic arcs did not produce bright spots where they crossed the upper arc of contact or the 22° halo, and the parhelic circle was not visible within the 22° halo. The accompanying sketch, in which spectrally coloured arcs or haloes are shown shaded, is a representation of the display as it appeared about 0810 G.M.T. Shortly afterwards it faded quickly, leaving only the upper arc of contact to the halo of 22°, which persisted until the afternoon, gradually becoming concave to the sun.

REFERENCES

1. London, Meteorological Office; Halo complex, 2 March 1954. *Met. Mag., London*, **83**, 1954, p. 186.
2. London, Royal Meteorological Society; The halo display of 2 March 1954. *Weather, London*, **9**, 1954, p. 206.

J. FINDLATER

[The oblique anthelic arcs seen by Mr. Findlater are very rare, especially when seen to extend to the vicinity of the sun. Visser[1] lists 33 observations of anthelic arcs, all which he could find recorded, in a paper published in 1936. Only six of these were of arcs extending to near the sun.

Optical theories of the formation of anthelic arcs have been given by A. Wegener,[2] whose theory, however, requires them to form an exterior arc of contact to the 22° halo at its highest point, and by Hastings.[3] Neuberger,[4] however, considers that these optical explanations are uncertain.

The solar elevation was about 32° 30′ at the time (0810 G.M.T.) of the phenomenon as shown in Mr. Findlater's diagram.

REFERENCES

1. VISSER, S. W.; Die schiefen Bogen der Gegensonne. *Met. Z., Braunschweig*, **53**, 1936, p. 336.
2. WEGENER, A.; Theorie der Haupthalos. *Aus d. Arch. dtsch. Seew., Hamburg*, **43**, Nr. 2, 1925.
3. HASTINGS, C. S.; A general theory of halos. *Mon. Weath. Rev., Washington, D.C.*, **48**, 1920, p. 322.
4. NEUBERGER, H.; General meteorological optics. Compendium of meteorology, Boston, 1951, p. 69.

Ed. *M.M.*]

Courses of training for voluntary observers

Thirty-four observers attended two courses, the first primarily for climatological and health resort station observers and the second primarily for agro-meteorological station observers, at the Meteorological Office Training School, Stanmore, at the end of September and beginning of October, 1959. Each course lasted 4½ days and consisted of instruction in weather observing and recording and instrument maintenance, supplemented by talks on the uses of climatological data in providing climatological services. There were discussions, and films and slides were shown. Visits were made to the London Forecast Office and to Harrow, where the work of the British climatology section, the punched-card installation and the instrument test room were seen and discussed.

These courses are designed to help the observers in their work, to give them a better idea of the uses to which their observations are put, to enable them to meet other observers and also to broaden their meteorological knowledge. It is hoped to arrange similar courses in October 1960.

OFFICIAL PUBLICATIONS

Changes in Meteorological Office series

The series *Meteorological Reports* and *Professional Notes* are being discontinued and replaced by a single series which will be entitled *Scientific Papers*. The last numbers of *Meteorological Reports* and *Professional Notes* to be published will be Nos. 21 and 22 and Nos. 124 and 125 respectively. These numbers will be published in the near future. *Professional Note* 126 was published in January 1959. The new series will have a larger page size than the discontinued series in order to allow more space for diagrams. The first number of *Scientific Papers* is now in the press.

RETIREMENT

Mr. C. V. Ockenden, O.B.E.

The retirement of Mr. C. V. Ockenden in November 1957, from his post as Assistant Director (Observations and Communications) was recorded in an earlier issue of this Magazine, with some details of his official career. On 31 December 1959, he retired from his subsequent temporary appointment, which he held first in the Observations and Communications Division at Dunstable, and afterwards at the Meteorological Office at Southampton Airport.

It is for his work in the sphere of meteorological communications that Mr. Ockenden will be chiefly remembered. As a representative of the Meteorological Office he attended a number of international conferences covering a period of nearly 10 years from 1949, and at several of such conferences was elected chairman of telecommunications committees, where he became respected by his international colleagues as a quiet, tactful and well informed leader of their discussions. It was, doubtless, his experiences in that capacity which stimulated his interest in Esperanto, and in its possible adoption by the World Meteorological Organization, and this he made the subject of a letter in the February 1956 issue of the *Meteorological Magazine*.

By relinquishing his temporary appointment, Mr. Ockenden severs the last remaining staff link with the Meteorological Office of the pre-1914 era, having joined the staff at Kew Observatory in 1913, as earlier recorded. His friends and former colleagues will wish him a long and happy retirement.

METEOROLOGICAL OFFICE NEWS

Retirements.—The Director-General records his appreciation of the services of:

Mr. F. B. Swain, Senior Experimental Officer, who retired on 7 December 1959. He joined the Office in June 1920 as a Technical Assistant, after service

during the First World War in the Royal Naval Air Service and the Royal Air Force. For the first nine years he was associated with meteorological services for the Army. At the end of 1929 he was posted to an aviation outstation and, apart from a period between 1946 and 1948 at Headquarters in the branch dealing with services for the Army, Ministry of Supply and Royal Air Force Training Command, and in the British Climatological Branch, all his subsequent service has been spent at aviation outstations, including a tour of duty in the Middle East. From 1956 until his retirement he served at Gloucester. Mr. Swain has accepted a temporary appointment in the Meteorological Office.

Mr. F. D. Caine, Experimental Officer, who retired on 24 November 1959. He joined the Office in 1934 after service in the Royal Air Force as a wireless operator. All his 25 years' service has been spent at aviation outstations including two tours of duty overseas in the Middle East. From June 1958 until his retirement he served at Marham. Mr. Caine has accepted a temporary appointment in the Meteorological Office.

WEATHER OF SEPTEMBER 1959

Northern Hemisphere

The circulation over the hemisphere was much more meridional in character than usual, especially in the Atlantic and European sector. Anticyclones were centred over or near the North Sea almost continuously throughout the month and on the mean pressure chart there was a high with a central pressure of 1023 millibars centred off the east coast of England. Positive pressure anomalies occurred over Britain, Scandinavia, central Europe and the Balkans, reaching a maximum of +8 millibars over the North Sea. The deepest low on the mean chart was over north-west Russia and associated anomalies reached −10 millibars on the mainland south of Novaya Zemlya. The Iceland low was about 7 millibars deeper than average and centred a little further east than usual; negative pressure anomalies extended over much of the Atlantic west of 20°W. Over North America a westward extension of the subtropical anticyclone over the Atlantic gave anomalies of +3 millibars in north-eastern states of the United States of America and increased the southerly advection in that region.

The persistently anticyclonic conditions gave an unusually warm month over western Europe, with mean temperatures up to 3°C. above average in parts of England and France. Between about 15°E. and the Urals anomalous northerly advection was responsible for mean temperatures being 2° to 4°C. lower than usual. The abnormal warmth which had been present during much of the summer in the north-east of the United States continued during September, anomalies of +3°C. being reported from a number of stations. Over the remainder of North America temperatures were close to the seasonal values.

Over the United Kingdom, southern Scandinavia and much of central Europe it was a particularly dry month. Many stations reported rainfall amounts only 10 per cent of normal and at one or two places in the area there was no measurable rain at all. However, it was a wet month in northern Norway, Jan Mayen and the Faeroes. Totals were well above the average too

at many stations around the central and western Mediterranean, severe storms being largely responsible for falls of up to four times the normal amount.

An important feature of the weather in the United States was a hurricane which crossed the coast of South Carolina from the south-east on the 29th and subsequently moved on a northward curving track across North Carolina and West Virginia. Gusts of up to 140 miles per hour were reported and rainfall amounts along its path were as much as ten inches in places. Maximum winds decreased rapidly as the storm moved inland but both wind and damage were extensive along the Georgia–South Carolina coast. The south-west monsoon gave much heavier rains than are usual in September over much of West Pakistan and western India. On the 19th very bad flooding was reported in and around Bombay, making many thousands of people homeless. Two typhoons affected Japan during the month, both causing excessive damage and heavy loss of life.

WEATHER OF OCTOBER 1959

Great Britain and Northern Ireland

The warm sunny weather which had persisted with few breaks since the second week of May continued during the first week of October, but gradually broke up during the second and third weeks and the latter part of the month was generally changeable with strong to gale force winds and heavy rain in places.

During the first eight days an anticyclone was situated to the east of the British Isles and a warm southerly airstream covered the country. Weather was sunny and mainly dry, with afternoon temperatures reaching 80°F. or more at several places, although a cold front brought considerable thundery rain to south-west England on the 6th; 1·61 inches fell at St. Mawgan in 24 hours, while light rain at Plymouth and Torquay ended a dry spell which had lasted since 22 August.

On the 8th an intense depression, which had originated about a week earlier as a tropical storm off the American seaboard, approached the west of Ireland but later combined with a depression off Greenland to form a large low-pressure system which covered most of the North Atlantic. The following day the anticyclone over Europe moved away eastwards but another formed in the Norwegian Sea and persisted until the 12th. From the 9th to 12th shallow depressions moved across England and Wales bringing mainly light rain to most districts, although much of northern Scotland remained dry and many places there had no measurable rain until the 15th.

The fine weather returned on the 13th as the anticyclone moved south-east to southern Scandinavia. Afternoon temperatures reached 70°F. locally but there was fog at night which became widespread and dense in places on the 14th and persisted all day in parts of north-east England and the Midlands, and throughout the 15th also in south Yorkshire. On the night of the 17th–18th a vigorous depression brought gales to southern England and rain to most districts as it moved from Cornwall to the Wash. A gust of 70 knots was recorded at Culdrose and many places in the west had more than one inch of rain in 12 hours.

A week of moderate to fresh westerly winds followed. There were frequent showers with good sunny periods on the 19th, 20th and 25th, and belts of more continuous rain moved eastwards across the country on the 21st and 24th.

An intense and deepening depression which moved across Scotland on the night of the 26th was preceded by exceptionally large falls of pressure, heavy rain and gale-force winds. By noon on the 27th pressure at Kew had fallen 40 millibars in 24 hours. There were severe northerly gales behind the depression with heavy thundery showers; a gust of 90 knots at St. Abbs Head equalled the highest speed previously recorded during October by a normally exposed anemometer in the British Isles. The strong northerly winds and cold showery weather persisted throughout the following day, but thereafter weather was changeable during the last few days of the month with occasional rain or showers and some good sunny periods.

Temperature was considerably above the average at the beginning of the month; at Mildenhall on the 3rd it rose to 83°F., the highest temperature recorded in the British Isles in October since 1921. During the last week temperature was somewhat below average. Sunshine exceeded the average almost everywhere; at Kew it was the sunniest October since records began in 1881. Rainfall was 92 per cent of the average in England and Wales, 105 in Scotland and 122 in Northern Ireland. Less than 75 per cent occurred in the Upper Thames Valley, over much of East Anglia and around the Wash, but more than 150 per cent was recorded in eastern Cornwall, western Fermanagh and the southern part of Co. Down. A number of places in eastern England had no measurable rain from 14 August until 9 or 10 October.

Aphis infection was at its highest for many years, especially in the West Riding of Yorkshire. Potato crops were generally good although some scab was evident, and apple crops were better than expected. The second crop of strawberries had rarely been so good or so late and chrysanthemums were very forward. The rain during the latter part of the month was most welcome and led to a rush of planting spring cabbage.

WEATHER OF NOVEMBER 1959

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean†	Percentage of average*	No. of days difference from average*	Percentage of average†
	°F.	°F.	°F.	%		%
England and Wales ...	65	14	+1·0	127	+3	97
Scotland	62	12	+1·9	141	+4	90
Northern Ireland ...	58	25	+0·5	108	+2	115

* 1916-1950 † 1921-1950

RAINFALL OF NOVEMBER 1959

Great Britain and Northern Ireland

County	Station	In.	*Per cent of Av.	County	Station	In.	*Per cent of Av.
London	Camden Square Gdns.	2·49	96	*Pemb.*	Maenclochog, Ddolwen B.	18·22	260
Kent	Dover	6·66	181	*Cards.*	Aberporth	9·05	194
,,	Edenbridge, Falconhurst	3·66	97	*Radnor*	Llandrindod Wells	4·87	110
Sussex	Compton, Compton Ho.	4·91	113	*Mont.*	Lake Vyrnwy	6·09	87
,,	Worthing, Beach Ho. Pk.	3·85	112	*Mer.*	Blaenau Festiniog	13·53	115
Hants.	St. Catherine's L'thouse	4·34	120	,,	Aberdovey	6·85	155
,,	Southampton, East Pk.	3·82	106	*Carn.*	Llandudno	4·31	151
,,	South Farnborough	2·82	98	*Angl.*	Llanerchymedd	8·10	186
Herts.	Harpenden, Rothamsted	2·22	73	*I. Man*	Douglas, Borough Cem.	7·12	150
Bucks.	Slough, Upton	2·38	88	*Wigtown*	Newton Stewart	5·31	104
Oxford	Oxford, Radcliffe	1·76	68	*Dumf.*	Dumfries, Crichton R.I.	6·69	161
N'hants.	Wellingboro' Swanspool	1·74	72	,,	Eskdalemuir Obsy.	10·17	170
Essex	Southend W.W.	2·51	106	*Roxb.*	Crailing	4·34	177
Suffolk	Ipswich, Belstead Hall	2·23	90	*Peebles*	Stobo Castle	6·64	177
,,	Lowestoft Sec. School	2·71	100	*Berwick*	Marchmont House	4·90	164
,,	Bury St. Ed., Westley H.	1·89	72	*E. Loth.*	N. Berwick	3·75	160
Norfolk	Sandringham Ho. Gdns.	1·77	64	*Midl'n.*	Edinburgh, Blackf'd H.	4·45	184
Dorset	Creech Grange	4·34	97	*Lanark*	Hamilton W.W., T'nhill	4·32	113
,,	Beaminster, East St.	5·75	119	*Ayr*	Prestwick	3·93	110
Devon	Teignmouth, Den Gdns.	7·79	200	,,	Glen Afton, Ayr San.	7·50	124
,,	Ilfracombe	8·86	206	*Renfrew*	Greenock, Prospect Hill	7·12	108
,,	Princetown	17·04	166	*Bute*	Rothesay	5·90	101
Cornwall	Bude	7·41	188	*Argyll*	Morven, Drimnin	8·88	143
,,	Penzance	8·96	183	,,	Ardrishaig, Canal Office	6·88	92
,,	St. Austell	9·13	162	,,	Inveraray Castle	10·09	113
,,	Scilly, St. Marys	5·78	160	,,	Islay, Eallabus	6·46	111
Somerset	Bath	3·77	119	,,	Tiree	5·30	114
,,	Taunton	5·54	170	*Kinross*	Loch Leven Sluice	6·89	189
Glos.	Cirencester	2·83	84	*Fife*	Leuchars Airfield	4·97	196
Salop	Church Stretton	4·05	110	*Perth*	Loch Dhu	9·57	117
,,	Shrewsbury, Monkmore	2·57	104	,,	Crieff, Strathearn Hyd.	6·24	158
Worcs.	Worcester, Red Hill	3·94	163	,,	Pitlochry, Fincastle	4·93	141
Warwick	Birmingham, Edgbaston	4·33	137	*Angus*	Montrose Hospital	5·31	188
Leics.	Thornton Reservoir	2·66	96	*Aberd.*	Braemar	6·43	169
Lincs.	Cranwell Airfield	1·95	84	,,	Dyce, Craibstone	4·99	141
,,	Skegness, Marine Gdns.	2·07	90	,,	New Deer School House	6·48	170
Notts.	Mansfield, Carr Bank	3·24	114	*Moray*	Gordon Castle	3·77	130
Derby	Buxton, Terrace Slopes	5·88	118	*Inverness*	Loch Ness, Garthbeg	5·17	126
Ches.	Bidston Observatory	3·96	142	,,	Fort William	10·46	133
,,	Manchester, Airport	3·33	110	,,	Skye, Duntulm	8·24	146
Lancs.	Stonyhurst College	5·15	109	,,	Benbecula	6·51	129
,,	Squires Gate	3·61	106	R. & C.	Fearn, Geanies	3·23	158
Yorks.	Wakefield, Clarence Pk.	3·16	123	,,	Inverbroom, Glackour	7·55	140
,,	Hull, Pearson Park	2·30	89	,,	Loch Duich, Ratagan	10·65	132
,,	Felixkirk, Mt. St. John	4·29	154	,,	Achnashellach	9·41	117
,,	York Museum	2·83	120	,,	Stornoway	6·83	152
,,	Scarborough	3·55	139	*Caith.*	Wick Airfield	4·27	135
,,	Middlesbrough	3·96	165	*Shetland*	Lerwick Observatory	5·61	121
,,	Baldersdale, Hury Res.	5·04	134	*Ferm.*	Belleek	6·27	127
Nor'l'd	Newcastle, Leazes Pk.	4·68	179	*Armagh*	Armagh Observatory	3·22	111
,,	Bellingham, High Green	6·70	201	*Down*	Seaforde	3·91	97
,,	Lilburn Tower Gdns.	6·53	207	*Antrim*	Aldergrove Airfield	3·08	97
Cumb.	Geltsdale	5·71	165	,,	Ballymena, Harryville	3·70	93
,,	Keswick, Derwent Island	7·87	125	*L'derry*	Garvagh, Moneydig	3·67	87
,,	Ravenglass, The Grove	7·22	160	,,	Londonderry, Creggan	5·28	121
Mon.	A'gavenney, Plâs Derwen	8·04	162	*Tyrone*	Omagh, Edenfel	4·71	113
Glam.	Cardiff, Penylan	4·94	113				

1916–1950